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The effectiveness of acoustic indices for forest monitoring in Atlantic rainforest fragments

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ABSTRACT

Forest monitoring is essential to maintain the integrity of protected areas, which has become a more pressing issue due to anthropogenic pressures and global climate change. Birds are widely used for this purpose, and as bird diversity is correlated with acoustic indices, it has been suggested that sounds can be used as an ecological indicator of ecosystem complexity and environmental changes. However, previous studies yield controversial results. Thus, we evaluated the effectiveness of six acoustic indices compared with the results obtained from a traditional point-counts survey for forest monitoring in an Atlantic rainforest fragment in Southern Bahia, Brazil. We also determined differences between acoustic indices calculated in the presence and absence of the researcher in the field to quantify the bias caused by human presence during data collection. There was a moderate correlation between the number of bird species just with the acoustic evenness index, from the six acoustic indices evaluated. We also determined that the presence of the researcher in the field at the point-count survey caused bias in acoustic indices. Therefore, more research must be done with autonomous recording units and the acoustic indices before they can be widely adopted for monitoring purposes in complex and diverse habitats such as the Atlantic tropical rainforest.

1. Introduction

Biodiversity monitoring is necessary to detect changes in ecosystem patterns (Noss, 1990; Hooper et al., 2012; Gardner, 2012; Siddig et al., 2016), which has become more pressing issue due to global climate change (Thuiller, 2007; Heller and Zavaleta, 2009; Urban, 2015; Ceballos et al., 2015). This monitoring supports the decision-making processes in public policies that aim for management actions to achieve goals established in international agreements on environmental conservation directives (UNEP, 2017). In this context, bird monitoring is considered as a suitable option (Koskimies, 1989; Bibby, 1999; Carignan and Villard, 2002; Krause and Farina, 2016), because birds are ecologically well studied (Birdlife, 2016) and respond to environmental changes over many spatial scales (Bregman et al., 2014). Changes in bird species composition and population dynamics might represent changes in environmental quality, as they respond to multiple environmental variables, such as natural resources supply, inter- and intra-specific interactions, habitat quality, and landscape configuration (Larsen et al., 2010; Carrara et al., 2015).

To establish an appropriate protocol for bird monitoring, it is necessary to consider characteristics such as team experience, equipment, permits, field effort, transport, and species detection by each method (Bispo et al., 2016). In tropical regions, the most used ornithological survey methods are audiovisual ones, such as point-counts, line transect, and complete list of species, which become more efficient when combined with sound recording (Larsen et al., 2016). Cost constraints, however, may be an obstacle to the implementation of such methods, which require logistic investments and specialists in fieldwork and statistics. Alternatively, there is an emerging method of bird monitoring, namely acoustic monitoring methods, using autonomous recording units (ARUs) (Brandes, 2008). The main advantage of ARU sampling is to simultaneously collect data at several points (Digby et al., 2013; Gasc et al., 2013). This automated technique also allows data collection in remote areas (Hutto and Stutzman, 2009), with minimum disturbance to wildlife (Acevedo and Villanueva-Rivera, 2006). Additionally, ARUs can be executed with a minimum of training, staff, and

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operative costs (Sueur et al., 2012).

By using ARUs the researcher can follow two approaches. The first is trying to identify the recorded species, using automated recognition software (Mammides et al., 2017). This approach, however, is relatively time-consuming in data processing (Hutto and Stutzman, 2009), and is not an appropriate approach for long-term community monitoring, because an automated recognizer is more restricted to the recognition of one or few species of interest (Alquezar and Machado, 2015; Mammides et al., 2017). The second approach, in turn, allows the researcher to determine acoustic indices from the ARU data.

Acoustic indices can be used for the determination of bird species diversity, based on the assumption that higher species diversity translates into higher acoustic complexity (Sueur et al., 2014). Usually, the studies using ARUs tried to compare species detection using this automated method with the data obtained when directed by researchers in the field (Shonfield and Bayne, 2017) and, so far, they have yielded controversial results. For instance, Boelman et al. (2007) recorded correlation between the bioacoustic index (BI) with direct ornithological survey methods in Hawaiian sub montane ecosystems. Pieretti et al. (2011) also found correlation between the acoustic complexity index (ACI) with avifauna counts in a beech mountain forest. Mammides et al. (2017), however, found low and sometimes controversial correlations between acoustic indices with the number of bird species in small fragments and large protected reserves of tropical rainforest.

As in these studies the authors aimed to compare the species' detection methods, they concomitantly conducted direct surveys with the ARU sampling. Thus, disturbance caused by the researcher can result in greater occurrence of alertness calls by some bird species, which make them more conspicuous, and in a bias toward point-counts survey, as verified by Digby et al. (2013). Furthermore, without the visual cues used during the point-counts survey (Leach et al., 2016), the researcher can miss species that vocalize just occasionally (Alquezar and Machado, 2015). It is possible, therefore, that in more biodiverse habitats, such as the subtropical forest studied by Mammides et al. (2017), the researchers' presence in the field caused higher disturbances in the bird vocal activity than in less complex habitats, such as the ones studied by Boelmam et al. (2007) and Pieretti et al. (2011).

The potential of the use of ARUs for long-term biodiversity monitoring in remote locations, however, is remarkable, as reviewed by Shonfield and Bayne, (2017), who claimed that this new methodology is more than simply a potential substitute for a human observer in the field. However, as highlighted by Mammides et al. (2017), the acoustic indices, as well as the autonomous recording units, should be tested in more environments to reveal their potential and limitations before they can be widely applied. Thus, in this study we aimed to compare the effectiveness of sampling birds by the traditional point-count survey with six acoustic indices calculated from ARU data in a tropical rainforest fragment. We predicted stronger correlations between the number of bird species determined by the point-count survey with the acoustic complexity index (ACI) and the bioacoustic index (BI), because both indices estimate the diversity of an acoustic community based on sound intensity variation, as verified in previous studies (Farina et al., 2011; Pieretti et al., 2011; Gasc et al., 2013). We also aimed to quantify the bias caused by human presence during data collection. Additionally, as a secondary result of the study, we compared the cost benefit between the point-count survey and the ARU method.

2. Materials and methods

2.1. Study site

The fieldwork was carried out in Serra do Teimoso Natural Reserve, an Atlantic rainforest fragment (UTM 24L 442733 E/8324297 S) in Southern Bahia, Brazil. The RST has a total of 200 hectares of hillside forest ranging from 250 to 850 meters above sea level. The surrounding landscape includes pasture areas, cacao under a shaded system, small crops, and forests in natural regeneration. The average annual rainfall is 1323 mm, relative air humidity in this area is around 84%, and the average annual temperature is 23.5 °C (Pinheiro et al., 2014). The RST is composed of ombrophilous forest and semi-deciduous seasonal forest. The vegetation is characterized by trees reaching up to 50 m in height, many vascular epiphytes and tree ferns. There are occurrences of wide tree trunks, some of them measuring more than 4.0 m in diameter, such as *Cariniana legalis* (the largest in Brazil, Thomas et al., 2009), *Plathymenia foliolosa*, *Lecythis pisonis*, *Centiarexylum myrianthum* and *Terminalia kuhlmannii*.

2.2. Point-counts survey

Just one researcher (FCJ) performed the point-counts survey at 12-point stations, following the protocol for bird monitoring in Brazilian reserves (Bispo et al., 2016), geo-referenced using GPS (Garmin eTrex Model 30), with spot heights ranging from 350 to 500 m above sea level. Each point was 200 m from the last and at least 100 m away from the forest edges (Bispo et al., 2016).

For nine consecutive days, each point was sampled for 10 min, allowing 10 min for displacement to the next point, totaling two hours of sample effort per day, from 6.20 am to 10.10 am, totaling 18 h of total field sample effort for point-counts survey. Following the protocol described by Bispo et al. (2016), the researcher sampled the points in a different order each day, following a pre-established sequence, without repeating the same point made on the previous day. At each point, the researcher recorded all individuals seen and/or heard. The observer also recorded bird vocalizations using a directional microphone recorder (model Tascan DR 44 WL). The sighted individuals were photographed when possible and identified following the guidelines for classification from the Brazilian Committee of Ornithological Records (Piacentini et al., 2015).

2.3. Autonomous recorder units (ARUs) sampling method

We performed the automated acoustic monitoring sample using nine ARUs, Song Meter Model SM2+ (Wildlife Acoustics Inc, Concord, MA, USA). However, one of them stopped during the recordings, so the data from this piece of equipment were not considered in the analysis. Trying to avoid recording human noise, such as the noise of breaking branches when stepping on the forest floor, we placed the ARUs along the 12-point stations described above, with 200 m between ARUs and 100 m from nearest point count. Each recorder was equipped with two omni-directional microphones (flat frequency response between 20 Hz and 20 kHz). The signals were sampled at 48 kHz and 16bits in wav format (Sueur et al., 2008).

We performed the ARU sampling method for 18 days. The first nine days were concomitant with the PC sampling. The data collected in the following nine consecutive days were used to test differences in acoustic indices calculated during the presence and absence of the observer in the field. During both sample periods, we scheduled ARUs to record from 6.20 am to 10.10 am, in 10 min recording followed by 10 min of pause schedule, 12 times, resulting in data collection of two hours per recorder, totaling 288 h of records.

2.4. Comparative costs of sampling methods

To determine the costs of the point-counts survey and the ARU sampling method, we considered the time of field sampling, time processing and analyzing data in the laboratory, considering the minimum wage of US$28.43/h of a biologist, determined by Brazilian law (#6884/79). We also included in the budgets the expenses with equipment, such as camera, lenses, and binoculars used in the point-counts survey, as well as Song Meter SM2+ recorders and microphones used for the ARU sampling. We excluded in both budgets the transport

expenses to the field site and mains-power to open trails, as they were the same for both methods.

2.5. Data and statistical analyses

Data collected using the PC sampling method were used to describe the bird community composition and to calculate the relative abundance (Pi) of each bird species by registering all species heard and/or sighted, following Bispo et al. (2016).

By the ARU sampling, we randomly selected 12 samples of 10 min of each ARU in two situations: (1) sounds recorded during the presence of the researcher in the field and (2) sounds recorded in the absence of the researcher in the field, totaling 96 samples in each situation. Before calculating these acoustic indices, we discarded the sounds generated by non-avian organisms, such as the 'chorus' of coastal black-handed titi (*Callicebus melanochir*), as well as sounds of crickets (Gryllidae spp.), cicadas (Cicadidae spp.), swinging branches, and vocalizations of domestic animals from nearby farms, such as the braying of donkeys, which were present in the sound records. Thus, we tested the correlations of those indices with the number of bird species recorded in the same sound sample. The number of bird species was determined by counting the species vocalization in each first minute of each 10-min sample. Thereafter, the acoustic complexity index (ACI) (Pieretti et al., 2011), the bioacoustic index (BI) (Boelman et al., 2007), the normalized difference soundscape index (NDSI) (Kasten et al., 2012), the acoustic entropy index (H) (Sueur et al., 2008), the acoustic diversity index (ADI) (Villanueva-Rivera et al., 2011), and the acoustic evenness index (AEI) (Villanueva-Rivera et al., 2011) were calculated for the same first minute of the 96 samples in both situations through the R software using the seewave, soundecology, and tuneR packages (R Core Team, 2016). The program converts the sound samples to mono and divides the 10-min samples into 10 samples of 1 min, which is a requirement for long files that are to be processed by the R software.

The ACI was calculated for the frequency range of 0–12.0 kHz, while the cluster size was adjusted to 10 s. The BI was calculated from 0.5–12.0 kHz and the limit of −50 decibels by software default. The H index was calculated in the frequency range 0–12.0 kHz. Both the ADI and the AEI were calculated in the frequency range of 0–12.0 kHz, using 1000 steps and the limit of −50 decibels by software default. The NDSI was calculated as the ratio ([biophony − anthrophony]/[biophony + anthrophony]) of the power spectral density values for the anthropophony (0–0.5 kHz) and biophonic (0.5–12.0 kHz).

To quantify the effect of the researcher's presence on acoustic indices, we used those 96 samples of 10 min in each situation and applied the Mann–Whitney test to compare the acoustic indices calculated with data obtained in the presence and absence of the observer in the field, using the Statistica v.7 (StatSoft, Inc.). Then, we tested the correlations between the number of bird species with each one of the six acoustic indices calculated for the same one-minute samples for each situation following Alquezar and Machado (2015). For these tests we calculated the Spearman rank coefficient correlation (r_S) using the BioEstat 5.0 software (Ayres et al., 2007). For all analyses $p < 0.05$ was considered significant.

3. Results

3.1. Point-counts survey

At the 12-point stations of the RST, 97 bird species were identified from 823 registers (Appendix A in Supplementary). The most frequent species recorded was *Thripophaga macroura* with relative abundance Pi = 0.066 (Table 1); the lowest abundance was Pi = 0.001 for a single-record species, such as *Campylorhamphus trochilirostris* and *Automolus leucophthalmus*. Some of the most frequently recorded bird species in the RST are classified as Vulnerable or Endangered according to the Brazilian Red List of Threatened Fauna (BRASIL, 2016), such as *Thripophaga macroura*, *Thamnomanes caesius* and *Caryothraustes canadenses* (Table 1).

Table 1
Relative abundance (Pi), vocalization frequency range (kHz) and conservation status of the 20 most frequently recorded bird species in September 2016 at the Serra do Teimoso Reserve, Southern Bahia, Brazil.

Bird species	Pi	Frequency range (kHz)	Conservation status*
Thripophaga macroura	0.066	0.5–20.0	VU
Setophaga pitiayumi	0.057	4.0–8.0	LC
Thamnomanes caesius	0.056	1.0–19.0	VU
Caryothraustes canadensis	0.046	2.0–16.0	EN
Pyriglena leucoptera	0.034	2.0–3.0	LC
Eupsittula aurea	0.031	2.0–11.0	LC
Pyrrhura leucotis	0.029	1.0–18.0	VU
Rhytipterna simplex	0.029	1.0–7.0	LC
Aratinga auricapillus	0.028	2.0–8.0	LC
Brotogeris tirica	0.027	1.5–13.5	LC
Ramphastos vitellinus	0.024	1.5–8.0	LC
Herpsilochmus rufimarginatus	0.023	2.5–5.0	LC
Conopophaga melanops	0.023	3.0–19.0	VU
Fomicarius colma	0.021	2.0–3.0	LC
Campylorhynchus turdinus	0.021	0.5–3.5	LC
Thamnophilus ambiguus	0.019	1.5–2.0	LC
Terenura maculata	0.019	3.0–9.0	LC
Lathrotriccus euleri	0.018	2.5–4.0	LC
Veniliornis affinis	0.017	1.5–18	LC
Chaetura cinereiventris	0.017	3.0–12.0	LC

* Conservation status: LC = Least Concern; VU = Vulnerable; EN = Endangered, according to the Brazilian Red List of Threatened Fauna (BRASIL, 2016).

In this Atlantic rainforest fragment, we recorded other bird species also classified as Endangered (EN) and Vulnerable (VU) (BRASIL, 2016). These species, however, showed low relative abundance values (Pi), EN: *Xiphorhynchus guttatus* (Pi = 0.005), *Dysithamnus plumbeus* (Pi = 0.005), and *Campylorhamphus trochilirostris* (P = 0.001); VU: *Xenops minutus* (Pi = 0.001) and *Amadonastur lacernulatus* (Pi = 0.001) (Appendix A in Supplementary).

3.2. Automated recording units (ARUs) sampling

Most of the bird vocalizations recorded in RST occupied frequency bands between 2.0 and 12.0 kHz (Table 1). Some of the recorded birds in the RST, such as *Glaucidium minutissimum*, vocalized in a narrow frequency range of 1.0–1.5 kHz (Table 1). However, the vocalizations of other bird species occupied a wide frequency range, such as *Thripophaga macroura* (0.5–20.0 kHz) and *Thamnomanes caesius* (1.0–19.0 kHz) (Table 1). With these recorded data we calculated six acoustic indices during both the presence (p) and absence (a) of the observer in the area (Table 2).

3.2.1. The effects of the researcher's presence on acoustic indices; and correlations between acoustic indices with the number of bird species

There were no differences between the acoustic indices ACI (U = 4605, $p = 0.50$), NDSI (U = 4445, $p = 0.33$), AEI (U = 4054, $p = 0.07$), and H (U = 4216, $p = 0.15$) calculated in the presence (p) or absence (a) of the observer in the field (Table 2). However, there was a trend (U = 4007, $p = 0.06$) toward higher ADI in the presence of the observer. Moreover, the BI was higher (U = 3709, $p = 0.001$), in the presence of the observer in the field than in his absence.

There were relatively stronger correlations between the number of bird species with the ACI and BI calculated in the presence of the observer in the field than in his absence (Table 3). In contrast, there were stronger correlations between the number of bird species with the ADI and AEI calculated in the absence of the observer in the field than in his presence (Table 3). There were poor and similar correlations for the

Table 2
Acoustic indices determined using the automated recorder units (ARUs) sampling method during the presence (p) or absence (a) of the observer in the field.

Descriptive Statistics	Acoustic indices*											
	ADIp	ADIa	ACIp	ACIa	NDSIp	NDSIa	AEIp	AEIa	Hp	Ha	BIp	BIa
Minimum	0.248	0.539	1796	1797	−0.11	0.04	0.001	0.001	0.915	0.841	25	16
Maximum	2.485	2.485	1854	1867	0.82	0.84	0.457	0.875	0.979	0.981	71	77
1st Quartile	2.465	2.469	1803	1803	0.50	0.44	0.011	0.006	0.957	0.960	40	35
3th Quartile	2.485	2.485	1813	1813	0.67	0.69	0.083	0.083	0.969	0.971	58	54
Median	2.481	2.484	1807	1807	0.60	0.60	0.038	0.021	0.965	0.966	48	43
Range	2.237	1.946	58	70	0.93	0.79	0.456	0.875	0.064	0.139	46	61

* ADI: acoustic diversity index; ACI: acoustic complexity index; NDSI: normalized difference soundscape index; AEI: acoustic evenness index; H: entropy index; BI: bioacoustic index. The acoustic indices were calculated from 96 samples of 1 min collected during point count sampling – presence (p) of the observer in the area, and 96 samples of 1 min collected after its completion – absence (a) of the observer in the area.

Table 3
Spearman rank correlation coefficients (r_S) of six acoustic indices with the number of bird species in the presence and absence of the researcher in the field.

Acoustic indices*	Presence		Absence	
	r_S	*p*	r_S	*p*
ACI	0.50	< 0.0001	0.29	0.003
BI	0.38	0.0001	0.28	0.005
AEI	0.29	0.004	0.46	< 0.0001
ADI	−0.25	0.014	−0.42	< 0.0001
NDSI	0.31	0.002	0.31	0.001
H	−0.14	0.16	−0.15	0.14

* ADI: acoustic diversity index; AEI: acoustic evenness index; ACI: acoustic complexity index; BI: bioacoustic index; NDSI: normalized difference soundscape index; H: entropy index.

NDSI in both situations, while there was no correlation between the number of bird species with the H (Table 3).

Furthermore, the correlations between the acoustic indices and the number of bird species varied considerably depending on the index examined and the situation (presence or absence of the observer) (Appendix B and C in Supplementary information).

3.3. Comparative costs of sampling methods

The ARU sampling method required less field time in total compared with point-counts survey. The same was recorded for the time spent on data processing and analysis in the laboratory, due to the use of the R software to process ARU records. The initial purchase costs of ARU sampling equipment, however, were higher than those for the point-count survey (Table 4).

Table 4
Comparative costs (US$) for execution of the point-counts survey and the autonomous recording units (ARUs) sampling method.

Item/Method (%)	Point-counts	Proportion (%)	ARUs	Proportion
Equipment	3160.00	27.9	12,320.00	91.4
Consumption material*	252.70	2.2	380.00	2.8
Field effort**	2046.43	18.1	255.87	1.9
Cost of stay***	158.00	1.4	48.00	0.4
Data processing and analyzing effort	5686.00	50.3	852.90	6.3
Total (US$)	11,303.13	100	13,476.77	100

* Notebooks, pencils, marking tape, memory cards, rechargeable, non-rechargeable batteries, and observer meals.

** Considering the minimum wage of a Biologist (R$90.00/hour c.a. US $28.43/h, according to Law # 6884/79 that regulates the profession of Biologist in Brazil).

*** Based on US$16.00/day or US$158.00/month.

4. Discussion

As far as we know, this is the first study comparing the composition of bird community by using point-counts survey and acoustic indices in the Brazilian Atlantic forest. Using the point-counts survey, we described 97 species in the bird community and determined the occurrence of 10 threatened bird species in the relatively small studied Atlantic rainforest fragment. We determined correlations between the number of bird species with five of the six acoustic indices calculated from using autonomous recording units (ARUs). We also verified, however, that these relationships varied considerably, in terms of the strength of the correlations, depending on the index examined and the situation (presence or absence of the observer in the field).

As we predicted, both the acoustic complexity index (ACI) and bioacoustic index (BI) showed correlations with the number of bird species. We expected this relationship due to the characteristics of both indices based on sound intensity variation, as well as due to the correlations verified in previous studies (Farina et al., 2011; Pieretti et al., 2011; Gasc et al., 2013). In the present study, however, the correlations were stronger at the presence of the researcher in the field and weaker ($r_S \leq 0.29$) in his absence. Disturbance caused by the researcher in the field could have stimulated birds for territorial defense, as reflected in the greater occurrence of alertness calls by some bird species, verified by Digby et al. (2013). Such a disturbance can also excite curiosity leading to other bird calls and songs, which were recorded by the ARUs, enhancing both ACI and BI. This explains the stronger correlations of the number of bird species with these indices, determined in the presence of the researcher in the field.

In surveys made in complex habitats similar to the site of the present study, Machado et al. (2016) in the Savanna biome in Brazil and Mammides et al. (2017) in small fragments and large protected reserves of subtropical forest in China, also obtained inconsistent correlations between ACI and BI and avian communities. Machado et al. (2016) did not recommend the use of ACI and BI in bird monitoring due to the great variation across their analyzed sites. In turn, Mammides et al. (2017) suggested that the ACI sensitivity to certain anthropogenic noises partly explains the low correlations in their results. Moreover, Mammides et al. (2017) also commented that their acoustic data were contaminated by sounds of insects, which contributed to the inconsistencies in the correlations determined by them for the BI with bird diversity.

In the present study, there were moderate correlation between the number of bird species and the acoustic evenness index (AEI). This relationship was stronger in the absence of the researcher field. During the bird dawn chorus, several bird vocalizations fulfilled different frequency bins in different frequency bands on the spectrogram, which characterized the low acoustic regularity as observed at the studied site, corroborating Fuller's et al. (2015) results. It should be emphasized that, unlike the other analyzed indexes, a lower AEI indicates better conservation conditions in an environment (Fuller et al., 2015).

Surprisingly, the acoustic diversity index (ADI), which was found to correlate positively with the number of bird species in other complex habitats (e.g. Machado et al., 2016; Mammides et al., 2017), showed the opposite correlation in our case. Usually, the ADI is higher as more frequency bands are filled due to the vocalization of more species (Villanueva-Rivera et al., 2011). In our records, however, the vocalizations of some bird species occupied a wide frequency range (Table 1), resulting in high ADI when there were just few species vocalizing, explaining the negative correlation between the number of bird species and ADI reported here. The index proposed is derived from the entropy index (H) (Sueur et al., 2008), which showed no correlation with the number of bird species in our studied site. We also found only weak correlation ($r_S = 0.31$) between the number of bird species with the normalized difference soundscape index (NDSI). However, the presence of the researcher in the field did not affect this index. Therefore, from the obtained results only support the use of the acoustic evenness index (AEI) as an ecological indicator of ecosystem complexity and environmental changes in threatened Atlantic forest fragments. Therefore, as previously stressed by Mammides et al. (2017), more research must be done with autonomous recording units and the acoustic indices before they can be widely adopted for monitoring purposes in complex and diverse habitats such as tropical rainforests.

As verified at the studied site, even a relatively small fragment of tropical rainforest contains nearly a hundred bird species, many of them threatened, which shows the importance of such monitoring. However, cost constraints may be an obstacle to the implementation of monitoring in developing countries, most of them in the tropical zone, where the biodiversity hotspot is located (Waldon et al., 2011). Our results showed that the ARU technique requires just 12.5% of the time needed for the field sampling in the traditional point-counts survey. Moreover, the time needed to obtain the acoustic indices required 13.6% of the time required for processing and analyzing data obtained from the point counts.

The long time spent on processing and analyzing data obtained from the PC sampling method is explained by the high diversity of repertoires and calls of tropical birds (Mathevon et al., 2008). This diversity leads to supplementary time spent on species identification. Hutto and Stutzman (2009) state that costs associated with equipment (ARUs) acquisition are not advantageous. Indeed, we verified that more than 90% of the total costs for the ARU sampling were spent on equipment. This equipment, however, can be re-used for further forest monitoring studies in several other sites.

5. Conclusions

By quantifying the bias caused by human presence during data collection we verified that among the six acoustic indices tested, just the acoustic evenness index (AEI) showed moderate correlation with the number of bird species and is effective in forest monitoring in Atlantic rainforest. Thus, important changes in this acoustic index during monitoring can be used to trigger local actions and prevent severe environmental impacts in threatened Atlantic forest fragments. Further studies must be done with autonomous recording units and the acoustic indices before they can be widely adopted for monitoring purposes in complex and diverse habitats such as Atlantic rainforests.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2018.04.001.

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